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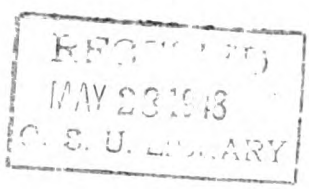

INTERPRETATION OF PERMISSIBLE LIMITS IN THE BREATHING OF TOXIC SUBSTANCES IN AIR

BY

H. H. SCHRENK

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INTERPRETATIONS OF PERMISSIBLE LIMITS IN THE BREATHING OF TOXIC SUBSTANCES IN AIR[1]

By H. H. Schrenk[2]

Much has been written and said concerning tables of permissible or maximum allowable concentrations of various toxic substances in air, but not enough attention has been given to their limitations and how to use them intelligently. There is a tendency to place too much reliance on figures, with little or no consideration of their real meaning. The repeated publication of a figure often adds significance to it far beyond that intended by the original author or publisher. How are these figures referred to as "maximum allowable concentrations" established? What is their real meaning?

To answer these questions it is necessary first to define maximum allowable concentration. The usual definition is somewhat as follows: "The average concentration to which an industrial worker can be exposed for 8-hours daily for an indefinite period without injury or occupational disease." This definition is made up of the following items: (1) Average concentration, (2) 8-hour day, (3) indefinite exposure period, and (4) lack of injury or occupational disease. There is some controversy regarding item (1), items (2) and (3) are usually though not invariably accepted, and there is definite disagreement regarding the interpretation of item (4).

To reach a more satisfactory interpretation of maximum allowable concentration, attention is directed to (1) the development of tables of maximum allowable concentrations, (2) criteria on which limits are based, and (3) methods used to obtain data on which limits are based.

Historical Development of Tables of Permissible Concentrations

One of the early tables and one referred to frequently was published in 1912 by Rudolf Kobert.[3] This table, prepared by K. B. Lehmann, is entitled "The Smallest Amounts of Noxious Industrial Gases which are Toxic and the Amounts Which May Perhaps be Endured." Concentrations are listed under four headings: (1) Rapidly fatal to man and animals, (2) dangerous in 1/2

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7457."

2/ Chief, Health Branch, Bureau of Mines.

3/ Kobert, Rudolf, Kompendium der praktischen Toxikologie zum Gebrauche für Arzte, Studierende und Medizinalbeamte (Compendium of Practical Toxicology from the Standpoint of the Physician, Student and Medical Official): Stuttgart, 1912, p. 45.

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to 1 hour, (3) 1/2 to 1 hour without serious disturbances, and (4) only minimal symptoms observed after several hours. It is evident from these headings that the values refer to acute effects and are based on toxicity. The table refers to 20 compounds, and it is interesting to note that the values for hydrochloric acid, hydrogen cyanide, ammonia, chlorine, and bromine as given under the heading "only minimal symptoms after several hours" agree with the values as usually accepted in present-day tables of maximum allowable concentrations for repeated exposures. It is also interesting to note that, with the exception of hydrogen cyanide, all of the gases have an irritating action. One other compound, carbon monoxide, has a value of 200 p.p.m., which does not greatly exceed the 100 p.p.m. usually accepted today, considering the fact that this value was published as early as 1912. However, the values for organic solvents such as benzol, carbon tetrachloride, chloroform, and carbon disulfide far exceed the values used today.

The next table, and one of the first to originate in this country, was published in Bureau of Mines Technical Paper 248[4/] in 1921. This table lists 33 compounds. Much of the information was taken from the table previously referred to, with additional information from various other articles. In this table also most of the figures refer to acute toxic effects, although some information is given on the least detectable odor and least amount required to cause irritation.

In 1927 Sayers[5/] published information on 27 compounds. The data refer to (1) percentage fatal in 30 minutes or less, (2) percentage causing dangerous illness in 0.5 to 1 hour, (3) percentage without serious effect for 0.5 to 1 hour, and (4) maximum safe concentration. It is not clear whether this latter classification referred to chronic or to acute poisoning. However, it is believed that it referred to acute poisoning. Also in 1927 Henderson and Haggard[6/] published information on some 25 compounds. Some of the values are listed as "maximum concentration allowable for prolonged exposure," and these values agree in most instances with values used today as maximum allowable concentrations. Other values are given for "slight symptoms after several hours exposure," and these values refer to acute exposures. In 1929 Sayers and Yant[7/] published a table which lists information as to the physiological response to various concentrations of some common gases and vapors. Seventeen compounds are listed, and the values in general refer to acute effects.

4/ Fieldner, A. C., Katz, S. H., and Kinney, S. P., Gas Masks for Gases Met in Fighting Fires: Bureau of Mines Tech. Paper 248, 1921, 56 pp.

5/ Sayers, R. R., Toxicology of Gases and Vapors: International Critical Tables of Numerical Data, Physics, Chemistry and Technology, New York, 1927, vol. 2, pp. 318-321.

6/ Henderson, Yandell, and Haggard, Howard W., Noxious Gases and the Principles of Respiration Influencing Their Action: New York, 1927, 220 pp.

7/ Sayers, R. R., Yant, W. P., Thomas, B. G. H., and Berger, L. B., Physiological Response Attending Exposure to Vapors of Methyl Bromide, Methyl Chloride, Ethyl Bromide and Ethyl Chloride: U. S. Public Health Service, Public Health Bull. 185, 1929, 56 pp.

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Schädliche Gase,[8] published in 1931, also contains a table of toxicity values ranging, in six steps, from concentrations immediately fatal to those endured for 6 hours without real symptoms. Twenty compounds are included in the table. The values definitely refer to acute effects.

In 1935 Sayers and DallaValle[9] published a table containing information on "Physical and toxic properties of common vapors and gases." The table lists 37 compounds and gives information on physiological response to 5 levels of concentrations. The first 4 refer to acute effects and range from concentrations that kill in a very short time to amounts causing slight symptoms after several hours' exposure. The final column, however, lists values for "maximum allowable concentration for prolonged exposure." Up to the time of the publication of this table the information given in the various tables undoubtedly referred to acute effects, even though some of the values, particularly those for several of the irritating gases, were the same as are used today for repeated exposures.

Since about 1935 most of the tables listing maximum allowable concentrations do not give a series of values for acute effects but only a single value which refers to repeated exposure. Such tables were published by Lehmann and Flury,[10] Bowditch and associates,[11] Gafafer,[12] Cook,[13] the American Conference of Governmental Industrial Hygienists,[14] and many others. The number of compounds has gradually increased, and some 140 compounds are now listed.

It is evident from the foregoing that our present tables of maximum allowable concentration have slowly evolved from earlier tables listing values pertaining primarily to acute effects and which might be considered as toxic limits. It is also evident that our present-day tables bear little resemblance to the earlier ones and contain values not based on toxic or pathological effects. However, the tendency to interpret them as relating to the toxic effect is still evident, as indicated by such statements as the

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8/ Flury, Ferdinand, and Zernik, Franz, Schädliche Gase: Berlin, 1931, p. 453.

9/ Sayers, R. R., and DallaValle, J. M., Prevention of Occupational Diseases Other Than Those That are Caused by Toxic Dust: Mech. Eng., vol. 57, April 1935, pp. 230-234.

10/ Lehmann, K. B., and Flury, F., Toxikologie und Hygiene der technischen Losungsmittel (Toxicology and Hygiene of Industrial Solvents): Berlin, 1938, p. 248.

11/ Bowditch, Manfred, Drinker, C. K., Drinker, Philip, Haggard, H. H., and Hamilton, Alice, Code for Safe Concentrations of Certain Common Toxic Substances Used in Industry: Jour. Ind. Hyg. and Toxicol., vol. 22, June 1940, P. 251.

12/ Gafafer, William M., Manual of Industrial Hygiene and Medical Service in War Industries: Philadelphia, 1943, 508 pp.

13/ Cook, Warren A., Maximum Allowable Concentrations of Industrial Atmospheric Contaminants: Ind. Medicine, vol. 14, November 1945, pp. 936-946.

14/ American Conference of Governmental Industrial Hygienists, 1947 M. A. C. Values: Ind. Hygiene Newsletter, vol. 7, August 1947, pp. 15-16.

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following: "Many of us feel that the codes on toxic limits. . ." Also, in some of the State codes, statements such as the following are noted: ". . . concentrations that equal or exceed the following, which constitute harmful exposures or harmful concentrations . . ." Also, one of the recent tables is headed "Toxic Limits of Various Substances." However, that others put a broader interpretation on the values is evident from the following: "A list of accepted and tentative values is also presented for practical use in the control of occupational disease and for the provision of both healthful and comfortable working conditions where toxic or obnoxious materials may be present," and "Considerable difficulty attends fixing. . . maximum allowable concentrations . . . because of . . . lack of uniform definition of the maximum allowable concentration concept. One concept is that the M. A. C. value should represent . . . that concentration at which a worker exposed for a sufficient period of time will just escape physiological or organic injury and occupational disease . . . A third concept is that the M. A. C. should perform the functions of the former concepts and in addition provide a working environment free of objectionable but non-injurious concentrations of smokes, dusts, irritants, and odors."

Therefore, in the evolution of tables of maximum allowable concentrations, values based on injury and occupational disease as well as values based on physiological effects and discomfort have been included. It might be well at this point to review briefly some of the criteria used in establishing permissible limits as well as the experimental procedures used to obtain the data on which the limits are based.

Criteria Used in Establishing Permissible Limits

At least three criteria have been used in establishing the maximum allowable concentrations now in use; these are (1) pathological effects, (2) slight physiological effects which apparently have no discernible untoward effects on health but cause impairment of coordination and reaction time and tend to make workers more prone to accidents, and (3) discomfort or sensory effects. In those cases where limits have been established on the basis of pathological effects, it is logical to assume that repeated exposure to concentrations significantly in excess of the allowable concentration probably would produce injury. Where the limit has been established on the basis of a slight physiological effect, it is not logical to assume that exposure to concentrations exceeding the allowable concentration would necessarily produce injurious effects. It is quite possible that the margin between a concentration that will produce mild response and the concentration that would produce injury would be large, in which case exposure to a concentration considerably higher than the allowable concentration might not be injurious to health.

The same is true for maximum allowable concentrations that have been established on the basis of sensory effects or discomfort. In this case the margin between sensory effects and actual damage to health may be even greater. It is obvious, therefore, that in using a permissible limit one must know the criterion used in establishing the limit. One obviously is not justified in assuming that a hazard to health exists because the concentration exceeds the maximum allowable. However, several of the state codes state that

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"concentrations that equal or exceed the following shall constitute harmful exposures or harmful concentrations." Even though maximum allowable concentrations were established with a high degree of accuracy, their interpretation must be based on the criteria used in establishing them. However, in addition to this factor one must also consider the limitations that are encountered in establishing maximum allowable concentrations and therefore it is necessary to discuss briefly the procedures used.

PROCEDURES USED IN ESTABLISHING MAXIMUM ALLOWABLE CONCENTRATIONS

Maximum allowable concentrations are usually established by one of the following procedures: (1) Laboratory tests on animals, (2) laboratory tests using human subjects, (3) field investigations, and (4) a combination of the above methods.

Laboratory Tests on Animals

Laboratory experiments with animals are one of the most commonly used procedures for establishing permissible concentrations and offers certain definite advantages. It is possible to control the exposures within rather accurately defined limits and to expose the animals to a wide variety of conditions. Such studies are helpful in demonstrating the nature of the damage likely to be produced, and indicate the type of response to look for in industry. By using a number of different types of animals, additional fundamental information can be obtained. The important disadvantage of the method is that it is not possible to interpret such data in terms of human response with a high degree of accuracy. This method is used particularly in establishing limits which are based on pathological effects. Limits which are established on the basis of animal experiments must be used with caution and careful observations of exposed persons should be made until experience indicates that the limit is satisfactory or should be revised.

Laboratory Tests Using Human Subjects

Laboratory tests using human subjects are usually made in establishing maximum allowable concentrations based on slight physiological effects and discomfort or sensory effects. Such tests are usually conducted after enough information has been obtained to indicate that such exposure of human subjects can be made with very little likelihood of injury to the subject, in other words, until evidence has been obtained that there is a definite margin between the mild physiological effect or sensory effect and possible injury. Limits based on this procedure should be fairly accurate but are subject to error, owing to the fact that the subjects usually are not accustomed to occupational exposure and therefore in some cases may tend to respond to lower concentrations than would persons working in industry. However, it is not necessary that these limits be established with a high degree of accuracy because the possibility of injury usually is not great.

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Field Investigations

Investigations are made in industry in which the concentration of contaminant in the work atmosphere is determined and correlated with the clinical and physical examinations of the workmen. This procedure has been used in establishing initial maximum allowable concentrations for some materials and is employed to check on previously established limits. Data of this nature are being continuously obtained by many organizations that have programs which entail air analyses and medical examination of workers. In one respect this procedure can be considered the most important in establishing maximum allowable concentrations since one is working with actual conditions in industry. At least two difficulties are encountered in applying the method: (1) Satisfactory sampling to obtain the average over-all exposure of the person, and (2) the difficulty of diagnosing injurious effects, particularly when they are of a mild or borderline degree and may be due to other factors, such as poor nutrition and general poor health. It is evident that if samples are not collected to give a good measure of over-all exposure one might set the limit too high if samples are taken at the source of contaminant and the person is not exposed to the higher concentrations most of the time and does not show signs of poisoning. Since a good average of over-all exposure is necessary in establishing the limit, obviously in evaluating exposure one should attempt to obtain a good measure of the over-all exposure.

Combination of Laboratory and Field Investigations

The most accurate maximum allowable concentrations are those based on both comprehensive laboratory investigations and field experience. However, regardless of the amount of information available at the time a permissible limit is established, it is always subject to readjustment if new investigations and experience indicate that the value is in error.

All maximum allowable concentrations are subject to the limitations of measuring accurately pathological or physiological response and also to the limitations of the methods for sampling and analysis of atmospheric contaminants. From a consideration of these factors, it is apparent that it is not possible to establish permissible limits with a high degree of accuracy. However, this need not detract from the use of such limits because the accuracy obtainable is satisfactory when permissible limits are used properly and are not employed for purposes for which they are not intended.

DISCUSSION

In applying maximum allowable concentrations to interpretation of the results of air analysis, it is necessary to understand the purpose and limitations of such values as well as the limitations of the sampling and analytical procedures. While their fundamental purpose is the promotion of health and efficiency, their practical use is for guidance in establishing control procedures to prevent harmful or objectionable concentrations from accumulating. Samples may be collected to ascertain the source of contaminants or to check on control procedure. For these purposes, only a few

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samples may be taken, the analytical procedure may be relatively crude, and in many instances satisfactory results may be obtained. On the other hand, if the purpose of the sampling and analysis is to obtain data for legal purposes or for correlation with codes, careful and thorough sampling should be carried out and accurate analytical procedures should be used. Should the results of such careful sampling and analysis give results which exceed the established maximum allowable concentrations, what interpretation should be put on them?

If the permissible concentration in question has been established on the basis of slight physiological effect or discomfort, one definitely is not justified in concluding that an occupational disease is likely to occur. The same is true even though the permissible limit is based on pathological effects because one must consider not only the extent to which the values have exceeded the maximum allowable concentration but also the time factor. These factors, for example, are taken into consideration in some of the State codes, which contain statements as follows: "Temporary concentrations in excess of the maximum allowable concentrations listed shall not be permitted if exposure to such concentrations for a period of one hour or less may result in an adverse effect on health . . ." In fact, one is not justified under any circumstances in using air analyses in conjunction with maximum allowable concentrations as a diagnosis of occupational disease, nor conversely, if values are less than the maximum allowable, as evidence that occupational disease cannot occur.

Obviously diagnosis of occupational disease should be based on a consideration of all factors, including careful clinical and physical examinations as well as air analyses and the fundamental physiological effects of the materials in question. Maximum allowable concentrations serve as a measure of exposure similar to the determination of lead or methanol in the urine or the determination of inorganic sulfates in the urine on exposure to benzol. When used in this manner it is not necessary to place so much emphasis on the absolute value of the maximum allowable concentration. Emphasis should be placed on interpretation. This should not be taken as a criticism of existing permissible limits or as an excuse for not establishing limits with as high degree of accuracy as possible. The values should represent our best judgment on the basis of available information and should be subject to change whenever additional experience indicates they are not satisfactory. Maximum allowable concentrations are an important tool of the industrial hygienist, and to obtain the greatest value from them they should be used properly.

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